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CORROSION TESTING BY THE UNDER-CAR METHOD DECEMBER 1978 TO MAY 1980

R.D. McDONALD and R.R. RAMSINGH
CORROSION SCIENCE SECTION

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CORROSION TESTING BY THE UNDER-CAR METHOD
DECEMBER 1978 TO MAY 1980

by

R.D. McDonald* and R.R. Ramsingh**

ABSTRACT

A series of under-car tests of 18-month duration is described. These tests included two winters and an intervening summer between December 1978 to May 1980. Specimens of automotive materials including standard commercial quality carbon steel, high-strength low-alloy steels, dual-phase steels, galvanized steel, zincrometal and aluminum were exposed during the test period.

Performance was assessed by comparing weight loss and pitting measurements.

Advantages of one steel with respect to another were shown by ranking them according to average corrosion rates. However, when ranges of corrosion rates are considered, advantages appear to be less significant.

Both aluminum and galvanized steel performed well during the test period. However, zincrometal provided good protection except at or near sheared edges.

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*Research Scientist and **Technician, Physical Metallurgy Research Laboratories, CANMET, Energy, Mines and Resources, Canada.

INTRODUCTION

Studies have been undertaken at CANMET to improve the strength and formability of metals for automotive use. The development of these alloys is expected to contribute to the goal of producing lighter automobiles with reduced fuel consumption. As a part of this work, the corrosion characteristics of these materials were evaluated and compared with those of commonly used automotive steels.

As described in a National Bureau of Standards survey (1), the use of road de-icing salts has resulted in severe corrosion of automobiles. It has been estimated that the cost of automotive corrosion caused by de-icing was between 6 to 14 billion dollars per annum in the U.S. A 1975 survey by the Canadian Ministry of Transport estimated that automotive corrosion in Canada cost about 2 billion dollars per annum. The imprecision of such estimates result primarily from uncertainties in estimating the useful lifetime of a car.

MATERIALS

The composition of the materials used for these tests are shown in Table 1. They consist of:

(a) a standard commercial quality cold-rolled carbon steel used as a "control" (CQCR), B;

(b) three high-strength low-alloy (HSLA) steels used in previous work (1);

(c) three dual-phase steels D/P, D/P1, D/P2;

(d) zincrometal, Z/M, a weldable steel product coil-coated with an epoxy Zn-rich primer;

(e) a commercial galvanized automotive steel (coating G90);

(f) an aluminum/steel pair coupled to produce galvanic effects, A/S;

(g) an aluminum alloy, 6010.

PROCEDURES

Method

The series of under-car tests described in this report follow procedures similar to those described previously (2).

Control specimens of steel B were mounted at the ends and the center of each rack. The remaining steels were mounted in an ordered manner so that each material, would not be limited to environmental conditions peculiar to any one position. This order was maintained throughout the test by the selective removal of specimens at 6 and 12 month intervals.

One rack of specimens was installed on the control arm of each car just forward of the rear axle (Fig. 1) on the side remote from the exhaust system.

The original specimens, on removal at the 6- and 12-month intervals, were replaced with new specimens to test additional materials or conditions not originally included. Distances travelled by each car during each interval, and in total, were recorded to permit an assessment of the effect of distance travelled on corrosive attack. These materials were:

Carbon steel B summer only, and winter '79-80 with 0.025 cm crevice (B'),
Two dual-phase steels D/P1 and D/P2,
Galvanized steel, G90 coat,
An aluminum alloy, 6010.

Specimens

Specimens with the dimensions shown in Fig. 2 were cut from rolled sheet 0.09 cm to 0.15 cm thick. Each specimen was made up of two coupons bolted together with a separation of 0.15 cm maintained by plastic washers between them. Rubber grommets were used to insulate the bolts, the two coupons were thus electrically insulated from each other preventing galvanic effects. An exception was the steel/aluminum couple for which steel rather than plastic washers were used to enhance galvanic action between the dissimilar metals.

Each coupon of a specimen was indented using an Olsen type of deep-drawing test machine with a ball of 2.22 cm in diameter. The depth of the indentation or cup was 0.64 cm for each of the steel specimens and 0.35 cm for each of the aluminum specimens. When assembled, the cupped regions of each section were placed downward and aligned with each other. The primary function of the cup was to provide a cold-worked region on each specimen, although it also served to retain "mud-pack" material that was subsequently collected and analysed for its salt content (2).

The surfaces of uncoated steel coupons were prepared with a light grit blast, using minus 150-mesh abrasive. The coupons were then vapour-degreased in trichlorethylene and weighed prior to assembly on the racks. Three specimens of each material were removed at 6- and 12-month intervals leaving at least one specimen per car* at the end of the 18-month period.

When the test was terminated, the racks were removed from the cars and photographed (Fig. 3). The specimens were then removed and dismantled for corrosion measurements.

Measurement of Corrosion

The corroded specimens of each material were cleaned as follows prior to reweighing and measurements of pit depths**:

Steel
- brushed with a stiff-bristled brush under running water
- the remaining corrosion products removed by immersion for 15 min in a 50% solution of concentrated HCL in distilled water with an addition of 1 mL/L of inhibitor Rodine 213
- rinsed and dried with alcohol in warm air;

Aluminum
- immersed in running tap water to remove loose grit
- ultrasonically cleaned in a detergent solution for 15 min
- ultrasonically cleaned in trichlorethylene
- rinsed and dried with alcohol in warm air;

Galvanized Steel
- dipped for about 5 min in an aqueous solution containing 150 mL of NH_4OH (s.g. 0.90) per litre of solution at room temperature then rinsed in water
- dipped for 15 - 20 s in a boiling aqueous solution containing 50g CrO_3 and 10g $AgNO_3$ per litre
- rinsed and dried with alcohol in warm air.

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*Nos. 1 to 6 identify either racks or cars interchangeably.

**ASTM Annual Book of Standards, Part 10, G 46.

ENVIRONMENT

Weather

The weather records for the Ottawa region for the months Dec 1978 to May 1980 are shown in Table 2.

The precipitation and the "degree days above 5°C"* should be of particular significance to the total corrosion during a winter season. The absence of "degree days above 5°C" shows that the daily mean temperature did not exceed 5°C during that month.

Salt Usage

Table 3 contains data provided by the Ontario Ministry of Transportation and Communications concerning the quantities of salt (NaCl) used on highways in the Ottawa area during the two winters 1978-79 and 1979-80, both as totals and as quantities per 2-lane kilometre.

Detailed data were not received from the City of Ottawa or from the Regional Municipality of Ottawa-Carleton. However, it was indicated by private communication with these sources that the following total quantities of de-icing salt were applied:

Year	Tonnes
1977-78**	32700
1978-79	34900
1979-80	23620

The rate of application of the salt, both for the region and the city, averaged 211 kg per 2-lane kilometre (750 lb per 2-lane mile). However, this rate was subject to some variations when conditions warranted.

On regional roads, salt and sand was applied alone or as a mixture of salt and sand in ratios 1:1 and 4:1. In the City of Ottawa, salt was applied both on its own and with sand.

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*1 degree day above 5°C describes a day when the daily mean temperature exceeds 5°C by 1°C.

**Included for comparison with (1).

RESULTS AND DISCUSSION

Weight Losses

Steel Specimens (18 months)

All weight loss results are listed in Table 4 for each rack (car). Results for control steel B indicate a slightly greater weight loss at the midpoint of each rack than at the ends.

In Table 5, the average weight losses of all steels on each rack, together with mileage and maintenance, show that the losses on rack 3 were considerably lower than on the others. This was attributed to the maintenance regime of car 3 which included warm, dry storage and frequent washing.

Table 6(a) is a summary of the weight loss of all the steels except B for the 18-month period, listed in increasing order. Steel B was omitted from this ranking because it had been removed after 12 months from cars 1, 2 and 3, Table 4(b), and because of the influence of the lower weight losses observed on rack 3. An estimate of the position of steel B in the ranking order after 18 months exposure was made by ranking all steels using only cars 4, 5 and 6 as in Table 6(b).

The rates of corrosion that occurred during consecutive intervals of the 18-month test period are shown in Table 7 in μm/a. These values were obtained from weight losses calculated for each interval assuming uniform corrosion. The rates are further illustrated in the chart shown in Fig. 4 and compared with some rates that occurred during short-term tests, Table 8.

There was no apparent influence on weight losses owing to greater distances travelled.

Steel Specimens (periods less than 18 months)

The results obtained for specimens mounted and exposed for shorter intervals are shown in Table 8. They include:

Summer only (June to Nov '79)

Steel B, control material.

Winter only (Dec '79 to May '80)

Steel B' - steel B with crevice spacing 0.025 cm

D/P 1 and 2 - dual-phase steels of different compositions from the D/P steel exposed for 18 months, Table 1.

When specimens of the control steel B were exposed during the summer only, Table 8, the average weight loss was 4.0 mg/cm^2 representing a rate of 10.2 μm/a.

Steels B and F, appeared to have similar corrosion characteristics when compared after 12 months if rack No. 3 is omitted, Table 4(b). Therefore, steels B and F were used interchangeably to assess the effects of a prior winter exposure on weight losses during subsequent summer and winter exposures. The weight loss of 4 mg/cm^2 for steel B exposed during the summer only, Table 8, when compared with the weight loss of 1.1 mg/cm^2 for steel F, Table 7, during the summer interval, indicates a substantial reduction in weight loss during the summer after prior winter exposure. This was also indicated by the low corrosion rates observed for other steels during the summer interval, Table 7. In addition, the lower weight losses observed during the second winter '79-'80 demonstrates a reduction in rate of weight loss for the second consecutive winter season as a result of prior exposure. Palmer (3) observed that prior exposure of specimens for several months under unsalted conditions appeared to reduce the corrosion rate during a subsequent exposure to de-icing salt.

Comparisons of steels D/P with D/P$_1$, and D/P$_2$ and B with B' cannot be made directly because there was insufficient room on the racks for both B and B' specimens during the final winter season '79-'80 of the 18-month period. However, comparing steel B' for '79-'80 (20.3 mg/cm^2) with steel B during the '77-'78 winter (19.7 mg/cm^2) (2) indicates that reduced crevice space had a negligible effect and that B and B' may be interchanged for this comparison. Further comparison of F, Table 7, and B, Table 8, with the dual-phase steels through the winters of '78-'79 and '79-'80 indicates that D/P$_1$ and D/P$_2$ were less sensitive than D/P to a de-icing salt environment, not-withstandings the apparently more severe period of '78-'79.

Aluminum and Coated Specimens

Other results that cannot be compared directly in terms of weight loss with the specimens shown in Table 4 are:

1. Z/M (zincrometal);
2. Aluminum alloy, 6010, exposed during winter '79-'80;
3. Aluminum in the A/S (aluminum/steel) couple;
4. G90 galvanized coat, specimen H.

1. Zincrometal specimens were assembled with the coated surfaces on the crevice side. The coating was undermined by ingress of corrosion over a distance of about 0.3 cm from the sheared edges. The remaining parts of the surfaces were well protected by the coating apart from some exposed areas on the cold-worked cups.

2. The aluminum alloy showed weight losses of less than 1 mg/cm^2, Table 8, similar to results observed for aluminum specimens exposed during the winter '77-'78 (2).

3. The results evaluated for the aluminum coupon in the A/S couples, Table 4, show a slight weight gain, generally less than 1 mg/cm^2. This was attributed to strongly adherent corrosion products and showed no consistent trends over the three seasonal intervals. For the A/S galvanic couple, a consistently smaller weight loss of the steel B coupons was observed when compared with control specimens of steel B. This suggests that some galvanic protection was provided by the aluminum coupon. The regions near the bolts showed both pitting in the aluminum coupon and rust stains. The areas of the aluminum more remote from the bolts remained relatively bright but with some rust staining.
   Aluminum is sufficiently electronegative to provide some protection for steel (4). However, an aluminum oxide film may prevent protection of the steel until it is penetrated. This could result in initial rust staining in areas where cathodic protection may subsequently be provided by the aluminum. It has been shown by laboratory methods (5) that corrosion of aluminum in an A/S couple is a minimum under approximately neutral pH conditions. In acidic or alkaline conditions, the rate of corrosion of aluminum increases.

4. Galvanized specimens H showed a weight loss on most of the six racks after 18 months. The maximum loss observed was about 40% of the original weight of a G90 galvanized coat. The losses were not uniform over specimen surfaces. The galvanized coating was detached and light rusting had occurred in areas adjacent to sheared edges and on the bottom surfaces of coupons with the greatest weight loss. For the most part, either zinc and/or intermetallic Fe/Zn alloy remained where rusting did not occur. Extrapola-

tion of the rate of coating loss indicated that an unpainted coat would have lasted for about five years. Experience with galvanized coats indicate that a substantially longer period of protection can be expected after the zinc layer is removed owing to the remaining intermetallic layers. The major component of the corrosion product, $Zn_5(OH)_8Cl_2$, was identified by X-ray diffraction.

Pitting

Steel Specimens

Pitting attack was evaluated for three intervals during the period December 1978 to May 1980 and is summarized in Table 9. These values, further summarized in Table 10, indicate that the greatest pitting occurred during the first winter-spring exposure of new specimen surfaces. Pitting progressed more slowly during the summer interval with a still further reduced rate of pitting during the second winter-spring interval. The average pitting depths for the interval December 1978 to May 1979 were reasonably consistent with those experienced in a previous 6-months test during December 1977 to May 1978. Pitting depths of 104, 116 and 129 μm were measured in steels F, G and J, respectively (2) for the December 1977 to May 1978 period.

The three materials, F, G and J, with similar pitting severity, maintained the same ranking through the three test intervals as shown in the earlier work (2). The standard control material, B, gave a similar performance to steels F, G and J, Table 9. The poorest performance in each test interval was given by the dual-phase steel, D/P, whereas the steel coupon in the aluminum/steel (A/S) couple ranked best in the first 6-month interval and for the entire 18-month period. This suggests that the aluminum provided some degree of galvanic protection, although the maximum depths of pitting were not reduced.

The dual-phase steel, D/P, appeared noticeably more prone to pitting than D/P1 and D/P2, added during the last test interval, Table 10. The average pitting depth for D/P during the first six months was 170 μm and for the entire test period was 207 μm. In comparison, D/P1 and D/P2 showed pitting depths of 94 and 97 μm for the final six month interval, Table 10. This observation is supported by the comparison of B and B' in Tables 9 and 10 with that of the three dual-phase steels. Steels B and B' are regarded as similar, as there was no appreciable effect in using a different crevice spacing.

Aluminum and Coated Specimens

1. Zincrometal gave continuing protection apart from the sheared edges of the coupons and in the cup where the coating was lost and rusting was visible. Pitting was negligible in the exposed areas.

2. The aluminum alloy coupons exposed during the last interval, Dec 1979 to May 1980, showed only minor pitting and staining (Fig. 5), with the exception of the specimen from rack 4. On this rack, all surfaces of the aluminum specimen tended to be equally pitted with the greatest depths, up to 105 μm, found on the upper surface.

3. On the A/S couple, the aluminum coupon was uppermost. Although the coupon did not pit on the upper surface, it did pit quite severely on the interface surface with the steel (Fig. 5). However, both the average, and the maximum pit depth tended to be less than 60% of the corresponding depths observed on the adjacent steel surface. An exception was rack 5 where no significant pitting was observed on either surface of the aluminum coupon.

4. Galvanized specimen, H, as expected, showed no evidence of pitting in the underlying steel over the 18-month test period, although some loss of coating down to the steel, occurred adjacent to the sheared edges.

SUMMARY

The results of the under-car corrosion tests can be summarized as follows:

1. Relative ranking of HSLA steels F, G, and J, in terms of weight loss and pitting severity, remained the same after the 18-month test as they were after a 6-month test (2).

2. The pitting and weight loss characteristics of control steel B resembled the better HSLA steels for the shorter exposures but became similar to J, the poorest HSLA steel, for the longer 18 months exposure.

3. Weight losses at the mid-positions of the racks tended to be consistently slightly greater than at either end.

4. The coating on a galvanized steel continued to provide good protection throughout the 18-month test period, although weight losses up to about 40% of the original G90 zinc coat occurred. The greatest attack took place on some creviced surfaces.

5. The original dual-phase steel, D/P, had a poor ranking. Its performance was similar to steel J in both weight loss and pitting.

6. Although a direct comparison of D/P_1 and D/P_2 with D/P and HSLA steels F, G and J was not possible, weight loss and pitting results show that D/P_1 and D/P_2 have an appreciable advantage. This was substantiated by weight loss tests in the laboratory (6).

7. Coupling aluminum to steel appeared to provide a small degree of galvanic protection but did not change appreciably the general corrosion behaviour of the bare steel in these tests. Some pitting may occur on the crevice face of the aluminum coupon, the region adjacent to the washer being the most severely attacked.

8. The aluminum alloy exposed during the winter 79-80 showed staining but no appreciable weight loss or pitting, apart from rack 4, which confirmed the results of a similar 6-month test during 1977-78 (2).

9. Zincrometal provided excellent protection over most of the surface, but deteriorated seriously at sheared edges.

10. Specimens from car 3, as shown previously (2), showed appreciably lower weight losses and depths of pitting than specimens from the other cars. This performance may be associated with the weekly washing and the warm, dry storage regime of car 3.

11. The distance travelled showed no consistent effect on the degree of corrosion occurring during the 18-month period within the limits of these tests. This corroborates previous results (2).

12. Prior exposure during the first interval evidently caused a reduction in corrosion rates during the second and third intervals.

13. The under-car test method used for these tests provides a reasonably consistent method of rating the resistance of materials to the corrosive road environment caused by de-icing salts.

ACKNOWLEDGEMENTS

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Table 1 - Composition of materials used for under-car corrosion test (1978-1980) (weight percentage).

Code	C	Mn	Si	S	P	Sn	Ni	Cr	Mo	V	Nb	N	Al	Cu
B (CQCR)	0.35	<0.003	0.015	0.005	0.005	0.025	0.03	<0.010	<0.005		<0.005	0.04		
F	0.09	0.54	0.095	0.015	0.009	0.007	<0.005	0.055	0.195	0.08	0.015		0.045	0.02
G	0.08	0.51	0.14	0.013	0.007	0.005	<0.005	0.06	<0.005	0.065	0.03		0.05	0.26
J	0.085	0.56	0.125	0.014	0.007	0.007	<0.005	0.055	0.01	0.085	0.02		0.04	0.02
D/P	0.095	3.08	0.3	0.016	0.007								0.05	
D/P_1	0.05	1.17	1.13	0.014	0.010			0.51	0.02				0.03	
D/P_2	0.07	1.03	1.11	0.013	0.010			0.54	0.42				0.04	
Al alloy	Alloy 6010 (Al, 1.0 Si, 0.8 Mg, 0.37 Cu)													
H	Galvanized steel sheet - G90 coat													
A/S	Aluminum/steel couple (steel as for B above)													
Z/M	Commercial zincrometal coat on one side													

Table 2. Weather records for the Ottawa region, Dec. 1978 to May 1980.

Station Ottawa	Temperature °C										Degree Days * Above 5°	
Month	Mean	Difference from normal	Maximum	Minimum	Snowfall (cm)	Total precipitation (mm)	% of normal precipitation	Snow on ground at end of month (cm)	No. of days with precipitation 1.0 mm or more	Bright sunshine (h)	This month	Since Jan. 1
Dec '78 not available												
Jan '79	-9.6	1.3	6.5	-26.7	87.6	89.6	159	38	15	60	0.0	0.0
Feb '79	-13.9	-4.2	6.4	-29.8	20.4	28.4	52	38	5	152	0.0	0.0
Mar '79	0.6	3.7	15.7	-17.7	4.0	34.2	59	0	8	140	13.0	13.0
Apr '79	6.5	0.8	21.0	-7.0	7.4	93.0	142	0	11	186	79.9	92.9
May '79	13.4	1.0	31.5	0.7	0.0	101.2	146	0	12	209	259.9	352.8
June '79	18.1	0.0	31.5	5.2	0.0	97.8	132	0	11	274	391.6	744.4
July '79	21.8	1.3	32.4	7.0	0.0	48.8	60	0	5	299	521.9	1266.3
Aug '79	18.5	-0.7	29.0	5.0	0.0	103.6	120	0	12	232	420.2	1865.5
Sept '79	14.4	-0.3	28.3	0.0	0.0	87.6	107	0	8	187	Not provided	
Oct '79	8.0	-0.7	26.4	-2.2	11.0	94.2	141	0	16	91	"	"
Nov '79	3.6	2.0	15.6	-9.2	17.4	101.8	133	1	14	66	"	"
Dec '79	-4.7	2.9	7.9	-21.0	30.0	76.8	110	4	14	87	"	"
Jan '80	-8.4	2.5	9.5	-24.3	26.0	36.2	64	7	7	142	0.0	0.0
Feb '80	-9.5	0.2	8.9	-22.0	35.4	32.2	59	17	8	160	0.0	0.0
Mar '80	-2.7	0.4	11.8	-24.5	30.6	80.2	139	0	10	180	2.1	2.1
Apr '80	6.9	1.2	19.0	-5.6	1.0	89.2	137	0	12	158	76.7	78.8
May '80	13.7	1.3	28.0	2.6	0.0	52.4	76	0	9	274	269.4	348.2

*"1 degree day above 5°C" results when the daily mean temperature exceeds 5°C by 1°C.

Table 3 - Salt application, tonnes, Ottawa Highway Patrol Region of the Ministry of Transportation and Communications, Ontario.

Winter 1978-79*		Winter 1979-80*	
Date	Tonnes	Date	Tonnes
Dec. 9/Jan. 5	7461	Dec. 7/Dec. 21	2411
Jan. 6/Feb. 2	6912	Jan. 4/Jan. 18	2870
Feb. 3/Mar. 2	3007	Feb. 1/15/29	4093
Mar. 3/Mar. 30	963	Mar. 4/Mar. 28	3264
Total	18343	Total	12638

*Rate of Application - Highways 127 kg per 2-lane km (450 lb per 2-lane mile);
- Freeway 197 kg per 2-lane km (700 lb. per 2-lane mile).

Table 4(a) - Under-car tests.

December 1978 - May 1979 (6 months)

Rack No.	Br	Bm	Bf	Wt loss mg/cm^2 A/S$^+$	D/P	F	G	J	H	Distance km	Storage condition	Regular wash
1	NE**	NE	NE	+0.69 18.79	30.77	26.89	26.66	29.60	NE	13676	Unheated	No
2	NE	"	"	+0.18 18.05	30.35	Lost	26.94	28.47	"	11826	"	"
3	"	"	"	+0.08 11.78	16.02	14.49	14.69	16.59	"	6772	Heated -20°C	Weekly
4	"	"	"	+0.96 30.32	NE	NE	NE	NE	"	11770	Unheated	No
5	"	"	"	+0.56 19.13	"	"	"	"	"	13012	"	"
6	"	"	"	+0.07 24.33	"	"	"	"	"	3957	"	"
Av.	"			20.40	25.72	20.69(1)	22.76	24.89		10169		

(1) Weighting to account for lost specimen indicates a weight loss av. of 22.8.

Table 4(b) - December 1978 to December 1979 (12 months)

Rack No.	Br	Bm	Bf	Wt loss mg/cm^2 A/S$^+$	D/P	F	G	J	H	Distance km	Storage condition	Regular wash
1	27.38	32.92	26.96	NE	NE	NE	NE	NE	NE	20698		
2	27.24	27.72	26.92	"	"	"	"	"	"	24478	Winter as above plus summer conditions	
3	18.31	19.87	16.87	"	"	"	"	"	"	13419		
4	NE	NE	NE	"	34.48	30.27	30.89	31.92	"	24402		
5	"	NE	"	"	27.55	25.64	25.73	28.65	"	23939		
6	"	"	"	"	37.35	32.51	35.00	39.17	"	8327		
Av.	24.31	26.84	23.58	"	33.12	29.47	30.47	33.24	"	19210		

Table 4(c) - December 1978 to May 1980 (18 months)

Rack No.	Br	Bm	Bf	Wt loss mg/cm^2* A/S+	D/P	F	G	J	H	Distance km	Storage condition / Regular wash
1	NE	NE	NE	+0.33 26.21	38.04	32.19	33.14	45.23	9.1	26074	The conditions for the winter 1979/80 were similar to those shown for Dec '78 to May '79.
2	"	"	"	+0.99 25.65	38.27	28.29	34.80	34.51	9.4	33258	
3	"	"	"	+0.23 21.43	26.37	23.66	23.08	25.14	11.3	21475	
4	36.84	46.18	39.14	+1.05 37.83	39.59	36.59	38.73	47.93	Lost	35310	
5	22.88	35.28	27.91	+0.07 30.18	35.70	30.18	36.62	37.85	5.9	31042	
6	42.45	45.09	44.03	+0.49 34.96	46.26	38.65	43.72	42.07	11.8	13925	
Av.	37.38	42.18	37.03	29.38	37.37	31.59	34.67	38.20	9.50	26847	
		(Av. of B for 3 locations = 38.86)									

*Averages of top and bottom coupons which showed deviations less than ±2 mg/cm^2 from their means.

**NE - not evaluated.

+A/S - aluminum/steel couple.

•r,m, and f indicate rear, middle, and front of rack with reference to car, e.g., Br, Bm, and Bf.

Table 5 - Weight losses of all steels for 18 months as an average for each car with distance travelled and maintenance regime.

Car rack No.	Side of car	Weight loss mg/cm^2	Distance km	Storage	Wash
1	L	35.0	27,074	Unheated	No
2	R	32.3	33,258	"	"
3	L	23.9	21,475	Heated ~20°C	Weekly
4	L	40.4	35,310	Unheated	No
5	L	33.3	31,042	"	"
6	L	42.2	13,925	"	"

Table 6 - Summary of weight losses after 18 months for each steel in increasing order of average weight loss.

Material	No. of coupons	Weight loss range mg/cm^2	Average Weight loss mg/cm^2
		(a)	
A/S*	6	21.4 - 37.8	29.4
F	12	23.7 - 38.7	31.6
G	12	23.1 - 43.7	34.7
D/P	12	26.4 - 46.3	37.4
J	12	25.1 - 47.9	38.2
		(b)**	
F	6	30.2 - 38.7	34.1
A/S	3	30.2 - 37.8	34.3
B	18	27.9 - 46.2	38.8
D/P	6	35.7 - 46.3	39.2
G	5	36.6 - 43.7	39.7
J	6	37.9 - 47.9	42.6

*A/S aluminum/steel couple showing steel weight loss.

**Only racks 4, 5 and 6 included in this evaluation in order to rank material B.

Table 7 - Rates of Corrosion μm/a, calculated for consecutive intervals during the 18-month period*.

Material	Six months '78-'79 wt loss mg/cm^2	rate μm/a	6/12 (summer '79) wt loss mg/cm^2	rate μm/a	12/18 (winter '79-80) wt loss mg/cm^2	rate μm/a
B	NE	NE	NE	NE	8.2	21.0
F	26.9	68.3	1.1	2.8	4.9	12.4
G	26.8	68.1	1.5	3.8	9.4	23.9
J	29.0	73.8	1.3	3.3	12.2	31.0
D/P	30.6	77.7	0.5	1.3	6.9	16.8

*Racks 1, 2, 4 and 5 were used for these calculations to avoid weighting caused by rack 3.

Table 8 - Extra* short-term under-car tests.

Rack No.	Weight loss** of materials (mg/cm^2) Summer '79 only B	Winter-spring 1979-80 D/P1	D/P2	B'	Al
1	3.6	18.7	19.0	24.3	0.04
2	4.2	17.8	16.8	20.8	0.18
3	4.8	12.1	13.3	16.9	0.03
4	5.8	Lost	16.5	24.1	0.35
5	3.5	16.9	12.7	16.4	0.16
6	2.1	18.8	16.7	19.3	+0.03
Av.	4.0	16.9	15.8	20.3	0.18
μm/a	10.2	43.0	40.2	51.6	0.5

*Specimens added to vacant spaces after removal of original specimens at 6- and 12-month intervals.

**Averages of top and bottom coupons.

B' carbon steel coupon with reduced crevice space.

Table 9 - Summary of pitting severity of bare steels in increasing order of their average pit depths for all cars.

December 1978 to May 1979 (6 months)*

Material	Average depth (μm)	Deepest
A/S	100	180
F	119	170
G	128	175
J	148	200
D/P	170	285

*Racks 1, 2 and 3 only; F - 1 and 3 only; 10 pits each rack.

December 1978 to December 1979 (12 months)*

Material	Average depth (μm)	Deepest
B+	144	260
G	157	220
F	164	230
J	169	240
D/P	200	295

*Racks 4, 5 and 6 only; +B - 1 and 2 only.

December 1978 to May 1980 (18 months)*

Material	Average depth (μm)	Deepest
A/S	154	240
F	166	235
G	169	235
J	179	255
B	182	290
D/P	207	320

*All racks included except for steel B which has a lower ranking because of the omission of car 3.

Table 10 - Trends in pitting of steels based on averages from Table 9.

	6 months Dec '78 - May '79	6 months May '79 - Dec '79	6 months Dec '79 - May '80
	Continuous exposure (Av. depths in microns)		
A/S*	100	54 (12 months, May '79 - May '80)	
F	119	45	2
G	128	29	12
J	148	21	10
D/P	170	30	7

*A/S not evaluated during May '79 - Dec '79

	6-month periods only		
	Dec '78 - May '79	May '79 - Dec '79	Dec '79 - May '80
D/P1			94
D/P2			97
B'(smaller crevice)			124
B		94	-

Fig. 1. Photograph of a "rack" of specimens bolted in place beneath a car, near the rear wheel, on the left side. (neg 416)

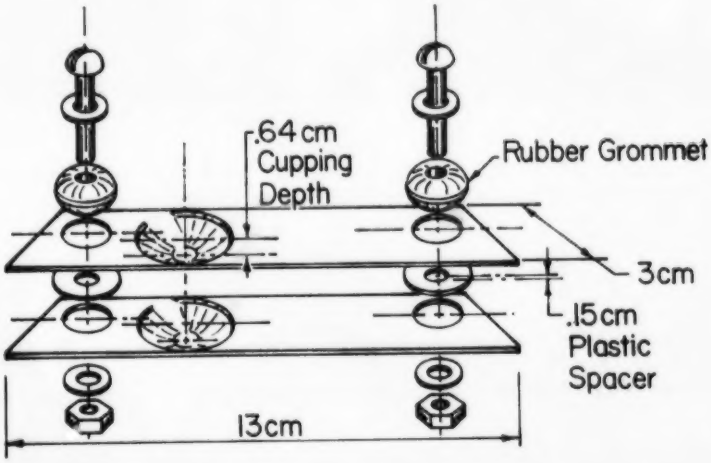

Fig. 2. Exploded view of specimens used for under-car tests. (neg 7826)

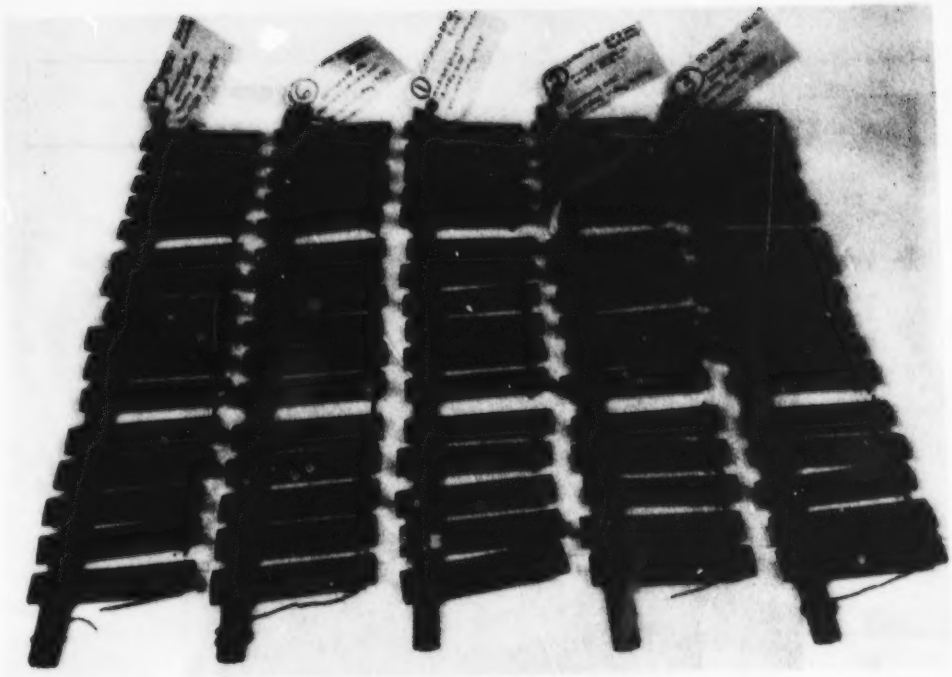

Fig. 3. Typical appearance of racks of specimens after removal from test cars (1). (neg 417)

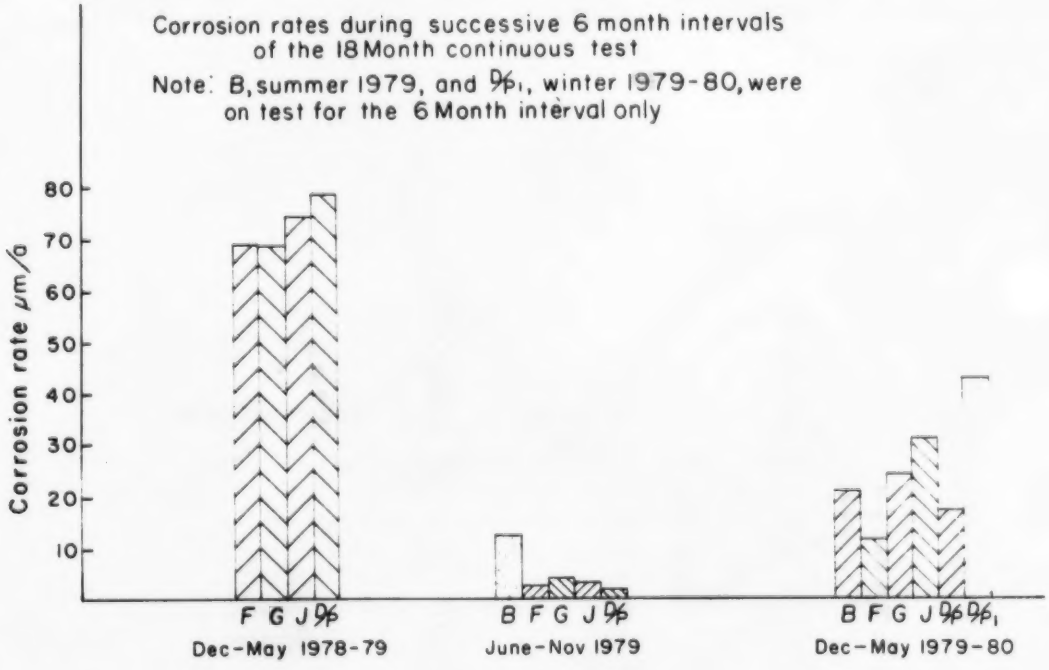

Fig. 4. Corrosion rates during consecutive intervals. (neg 7160)

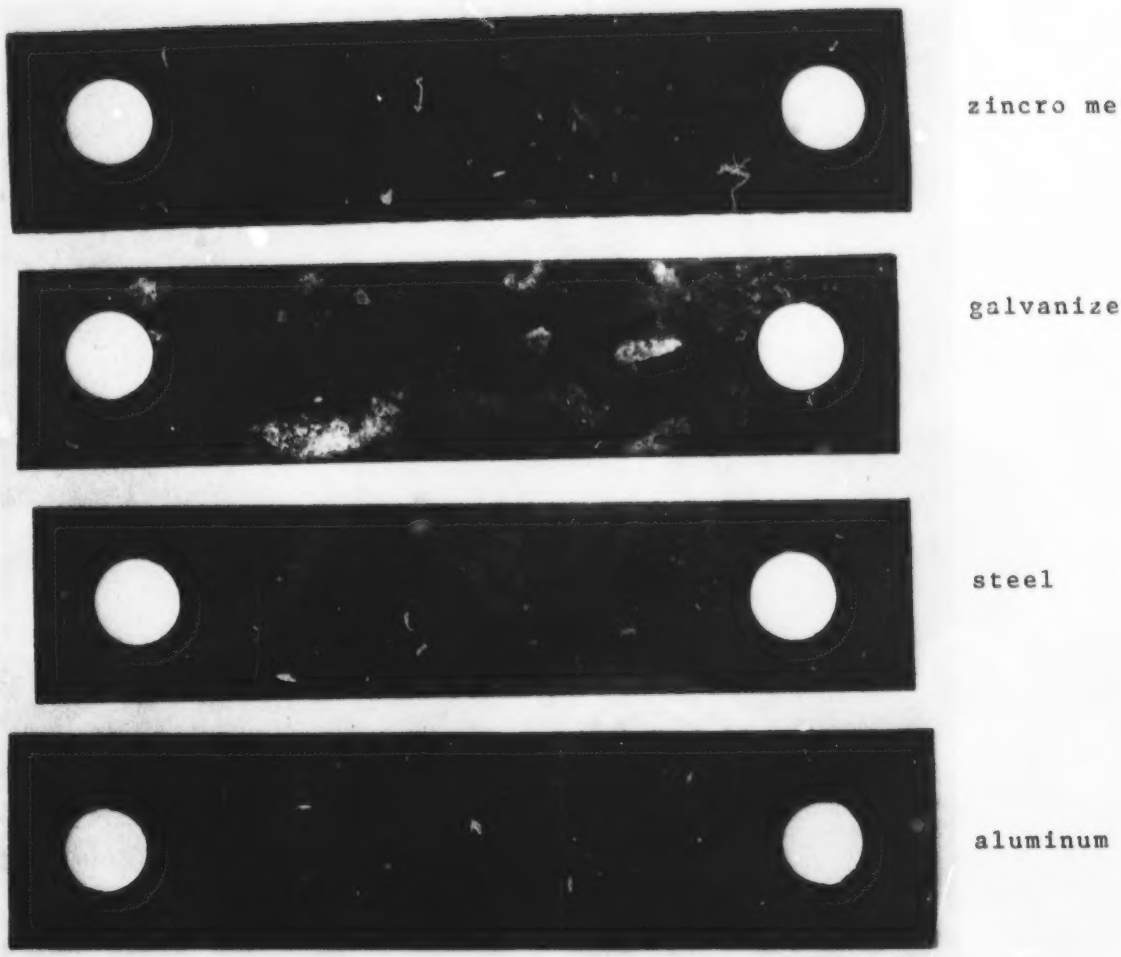

Fig. 5. Specimen after dismantling and cleaning showing the condition of the inner or crevice surface of coupons prior to weighing. (neg 5251)